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Long-term ecological monitoring on forest ecosystems in Indian Himalayan Region: Criteria and indicator approach

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ABSTRACT

The Himalaya, as provider of range of goods and ecosystem services, is vital for sustaining the life of billions of people. Recognition as one of the Global biodiversity hotspot implies its global significance. The forest ecosystems and plant biodiversity in the region is predicted to respond to the rapid warming and the human induced perturbations. However, documentation of these responses and likely consequences is meagre so as to provide a basis for future comparison. Realizing the importance of understanding relationships of climate change (CC) and forest biodiversity, systematic collection of data sets, covering various aspects of environment was attempted through establishing Long-Term Ecological Research (LTER) and monitoring. The LTERs in general, have emerged to be important to improve our understanding on spatio-temporal variations happening in a particular ecosystem. Indian National Action Plan for Climate Change (NAPCC) sets out National Mission for Sustaining the Himalayan Ecosystem (NMSHE) to conserve Himalayan ecosystem from the brunt of climate vulnerabilities. Considering importance of Himalaya forests and their sensitivity to CC impacts, NMSHE has stressed on undertaking Long-Term Ecological Monitoring (LTEM) and development of monitoring protocol with forest biodiversity specific parameters and indicators. In this context first of its kind attempt have been made to develop long-term ecological monitoring protocol along with suitable criteria and indicators for the Indian Himalaya, and demonstrate it through documenting base line data of established LTEM plots in diverse forest types in the Indian western Himalaya.

1. Introduction

Globally there are very few regions where climate change might be as rapid as evidenced in the Himalaya (Shrestha et al., 2012; Gottfried et al., 2012). This region, however, well recognized as (i) hotspot of biodiversity, and (ii) provider of range of ecosystem services. The growing vulnerability to CC impacts, accompanied by unsustainable harvesting of bio-resources to satisfy ever increasing demand of growing population, have caused serious concerns about Himalayan biodiversity (Singh et al. 1996; Chettri et al., 2015; Chakraborty et al., 2017). The Indian Himalayan Region (IHR) is recognized as forested landscape, however, high dependency of local inhabitants on forest resources (Rawal et al., 2012; Negi and Maikhuri, 2016; Negi et al., 2018), adverse impact of uncontrolled forest fire (Sharma and Pant, 2017), shifting cultivation, agriculture expansion and land use changes have been reported to cause unprecedented forest degradation, deforestation and biodiversity loss in the region (Reddy et al., 2013, 2016; Chakraborty et al., 2017). While environmental perturbations have been reported to change forest structure and functions (Gottfried et al., 2012), the anthropogenic disturbances are considered as the dominant driver of forest cover change (Pandit et al., 2007; Reddy et al., 2013, 2016). The phenomenon of climate warming and its impacts on forest ecosystems are now evident across the globe. IHR being highly vulnerable both due to natural and anthropogenic perturbations carries very higher probability of changes in the forest structure, composition, phenology, regeneration, shifting of species boundaries and functions of forest ecosystems (Ravindranath et al., 2005). Therefore, data/information collected over a long period becomes indispensable for evaluating the consequences of these changes and supporting decision making process for promotion of Ecosystem-based Adaptation (EbA). However, long-term data sets and documentation of ongoing consequences of environmental changes and ecosystem processes are scanty in the region, thereby making conservation efforts extremely difficult (Sekar et al., 2017).

Long-term Ecological Research (LTER) and monitoring are reported to provide key insights in ecology, environmental change, natural resource management and biodiversity conservation (Lindenmayer et al., 2012; Haase et al., 2018; Mirtl et al., 2018). The need for LTER has been

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recognized and promoted globally by United Nations Framework Convention on Climate Change (UNFCCC), United Nations Convention on Biological Diversity (UNCBD), and Intergovernmental Science Policy Platform on Biodiversity and Ecosystem (IPBES: Singh et al., 2012). Moreover, CBD also considers LTER essential for ensuring long-term ecosystem management and biodiversity conservation. Consequently LTER has emerged as one of the best approach for data collection, fostering collaboration among ecosystem and socio-ecological researchers, and developing networks (e.g. RAINFOR, NEON, ECN, TERN/LTERN, NCEAS, TEAM, DIVERSITAS, Fluxnet and Landsat Archives, SAEON, CFERN, CEOBEX, LTER-Europe, Exper-ER, GLORIA) globally (Fu et al., 2010; Fischer et al., 2010; Collins et al., 2011; Mirtl et al., 2018; Haase et al., 2018). Specifically on forest ecosystems, the long-term studies have been widely used to monitor changes in forest structure, composition and services (Hobbie et al., 2003; Phillips et al., 2009; Haase et al., 2018). Among others, RAINFOR in tropical forests of Amazonia, Hubbard Brook Experiment in US and Biodiversity Exploratories in Germany is most recognized and globally accepted LTER for understanding changes in forest dynamics and biodiversity conservation. Presently, over 20 countries fall under the umbrella of the International Long-Term Ecological Research (ILTER) network (Mirtl et al., 2018; Haase et al., 2018). Forest Global Earth Observatory of the Center for Tropical Forest Science (ForestGeo-CTFS) forms a well recognized network established across tropical and temperate regions for monitoring stand dynamics over a period of twenty or more years. Global terrestrial observing system (GTOS) is also among various long-term monitoring programmes for observations, modelling, and analysis of terrestrial ecosystems. It facilitates access to information on terrestrial ecosystems so that researchers and policy makers can detect and manage global and regional environmental change. GTOS also manages the Terrestrial Ecosystem Monitoring Sites (TEMS) database. In general, the information generated through LTERs has played significant role in policy planning for forest resource management and biodiversity conservation at local, regional and global scale (Phillips et al., 2009; Magurran et al., 2010; Fu et al., 2010; Chettri et al., 2015).

The forests in IHR, not only render a service of global relevance as major 'sink' for carbon dioxide, but also remain source of livelihoods for large population both in upstream and downstream (Reddy et al., 2013, 2016; Negi et al., 2018). Therefore, India's National Action Plan on Climate Change (NAPCC) considered this region vital for preserving the ecological security of India. This is because, nearly 42% of its geographical area is under forests representing one-third of forest cover of the country. In spite of the fact that a plethora of information is available on LTERs in different parts of the world, use of internationally accepted protocols for data collection and long-term forest monitoring has remained limited in India and particularly in IHR. Recognising this, NAPCC has set out NMSHE for safeguarding and sustaining the Himalayan ecosystem. Under NMSHE, there are six thematic study area/Task Forces, and Task Force 3 that is 'Forest Resources and Plant Biodiversity' is working on development of robust data base of flora, and long-term monitoring in forest ecosystem of the IHR.

2. Long term ecological research in India

India is a country with relatively high forest cover and a wealth of research relating to the biodiversity of Indian forests (Ratnam, 2014). However, there are few long-term forest monitoring sites where data is collected to match international protocols. Recognizing the importance and limitation of LTER network in India, Tripathi (2010) had highlighted the need for immediate attention either by joining the ongoing ILTER networks or by establishing its own network in different ecoregions of the country. Long Term Research Sites (LTRS) or Preservation Plots in India have three different names such as Linear Tree Increment (LTI), Linear Increment Plots (LIP) and Linear Sample Plots (LSP). The LTRS of India were mainly studied by Mathauda (1958) and Rai (1979, 1980, 1981). Rai (1996) has reported a total of 309 Preservation Plots, among which 187 are in natural forests and 122 in plantations covering an area of approximately 8500 ha in different forest types throughout the country. As a part of international network, a 50 ha permanent plot was set up during 1988–1989 in the deciduous forest of Mudumalai, southern India to study tropical forest dynamics (Sukumar et al., 1992). Single species plots were also established in many parts of the country i.e., sandalwood (Tamil Nadu, Karnataka, Andhra Pradesh); *Acacia catechu* and *Adina cordifolia* (Uttar Pradesh and Bihar); *Artocarpus kirsuta*, *Hopea parvipora*, and *Dalbergia latifolia* (Karnataka, Tamil Nadu, Kerala), although most of these plots have been lost due to degradation and anthropogenic pressure (Tewari, 2016). The major aim of establishing LTRS was to study the pattern of mortality and rate of diameter increment (Mathauda (1958) and basal area increment (Rai, 1996). However, the records of majority of reported plots are not available due the fact that the data from these plots were not analysed and have not entered the accessible scientific literature. Consistent monitoring since 1994 of tree mortality, recruitment and diameter growth in permanent plots established in tropical forests of Western Ghats is being done at an interval of four years (1998, 2003, 2007 and 2012: Ratnam, 2014).

Recently Ministry of Environment, Forest and Climate Change (MoEF&CC), Govt. of India, underlined the need for an extensive network of long-term vegetation plots to support effective CC mitigation and biodiversity conservation, and a programme 'Indian long term ecological observatories' has been launched (ILTEO, 2015). The major objective of this programme is to characterize how forest structure, species diversity, and biomass, changes across broad environmental gradients of the country (ILTEO, 2015). Few LTEM plots in the Himachal Pradesh (these were the only plots in IHR) have been established with a focus on increment in basal area, change in species richness and population density and chemical characteristics of the soil in the monitoring plots (Chawla et al., 2012). The knowledge gap on the LTER suggested to develop common protocol, criteria and indicators to make LTEM sites comparable across the diverse region of the country. Potential response of Himalayan forests is still less/not studied subject to know the likely changes in future due to climate change impacts. To meet the need for long-term studies in Himalayan region in general and forests in particular, present study focuses on (i) developing an approach for identification of criteria or parameters for forests which can be influenced by change in climate, (ii) developing important indicators to measure such changes in the Himalayan forests, and (iii) establishing base line data of LTEM plots in diverse forest types in the Indian western Himalaya. It is believed that a common protocol for establishment of LTEM sites in the IHR will be developed for comparable studies in diverse conditions, once criteria and monitoring indicators are identified.

3. Procedures and methods

Setting priorities, criteria and indicators forms the first step for establishing LTEM plots/sites in any region (Singh et al., 2012; Lindenmayer et al., 2012; Chettri et al., 2015; Mirtl et al., 2018). In this context, a National Workshop on 'Forest Resources and Plant Biodiversity', at GBPNIHESD, Kosi-Katarmal, Almora, Uttarakhand, was organized between 16 and 18 November 2016 to identify parameters or criteria and indicators for long-term monitoring of forests in the Himalayan region. The workshop was attended by over 120 participants from 20 research organizations/universities engaged in mountain-specific research in the Himalayan region. Previous work globally (Burns et al., 2014; Lindenmayer et al., 2012; Chettri et al., 2015; Mirtl et al., 2018), India (Rai, 1996; Sukumar et al., 1992; Singh et al., 2012) and from Himalayan region (Chawla et al., 2012; Chettri et al., 2015; ILTEO, 2015) were also reviewed to discuss criteria and indicators during the workshop, and an approach was developed for execution of long-term monitoring in the IHR (Fig. 1).

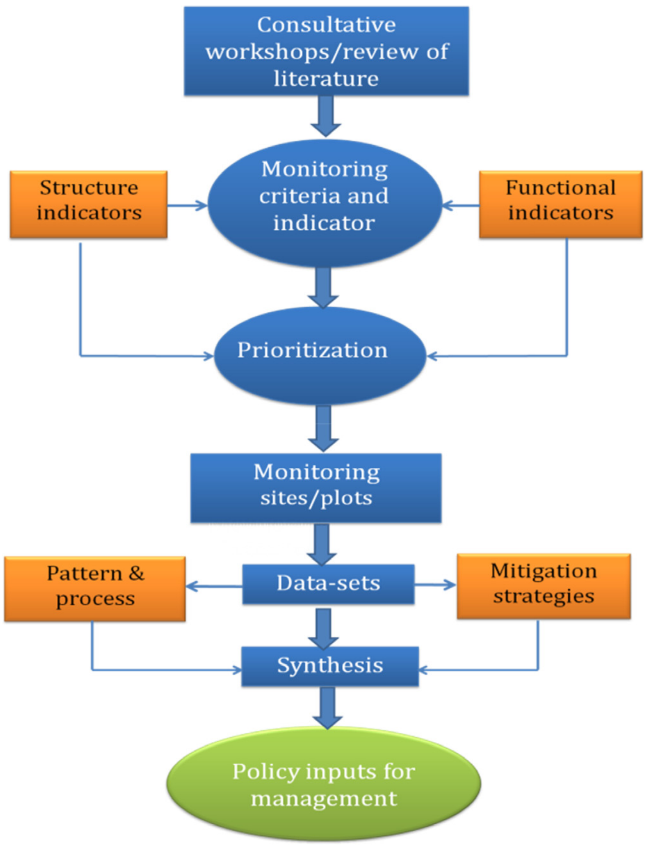

Fig. 1. Approach for long-term ecological monitoring on forest ecosystems.

3.1. Criteria and indicators for LTEM

The criteria and indicators approach provides a tool for assessing the changes in given forestry situations, and this provides information to forest managers for management planning (Rawat et al., 2008). Castenada (2000) defines criteria as the range of forest values to be addressed and the essential elements of forest management against which the sustainability of forests may be assessed. In the present study, criteria define and characterize the essential elements or parameters, as well as a set of conditions, by which long-term changes may be assessed. Indicators are measure of criteria in quantitative and qualitative attributes and that helps to monitor trends of changes over time (Yoccoz et al., 2001; Lindenmayer and Likens, 2010; Chettri et al., 2015). Earlier literature on LTER in India (Rai, 1996; Sukumar et al., 1992; Singh et al., 2012; ILTEO, 2015 and IHR (Chawla et al., 2012) was also reviewed for finalization of criteria and indicators.

The results of review provide six major monitoring parameters i.e. rate of basal area increment, monitoring mortality, species richness, forest structure, biomass and soil nutrients.

Basal area is a common criteria selected by all the earlier studied for monitoring in LTEM plots: it is an important criteria for monitoring as the knowledge of rate of basal area increment of a species or forest community is vital for forest management and plantation programme (Rai, 1996; Chettri et al., 2015). Species composition of forest, changes in space and time, while nativity of species indicates stability of a particular ecosystem to environmental changes. Recruitment of seedling and conversion of saplings into trees, and population structure provides distribution of individuals in different tree class in the forest ecosystem (Tesfaye et al., 2002; Gairola et al., 2014). Rarity and representative species indicates uniqueness of a particular landscape or ecosystem. Carbon based ecological indicators are useful for quantification of three specific ecological indicators [net primary productivity (NPP), net ecosystem production (NEP), net biome production (NBP)] that relate global carbon (C) budgets to the long-term sustainability of forest ecosystems under changing environment. Soil nutrients i.e. carbon (C), nitrogen (N) and phosphorus (P) are important parameters since they limit plant growth and different biological processes. After a thorough discussion on above parameters, and feasibility of the work in diverse condition of mountains, 15 criteria and related indicators were identified for long-term monitoring (Table 1).

3.2. Levels and components of monitoring

While considering the parameters of monitoring in selected plots, the level of measurement are proposed i.e. species, communities, habitats and landscapes for detail study as follows:

I. *Species level monitoring:* this includes population status and dynamics of selected Rare, Endangered, Threatened (RET) and endemic species following IUCN regional guidelines. Population dynamics of high value plants (economic – medicinal, edible, etc.; ecological – native and endemic) under each monitoring plots will be monitored.
II. *Community level monitoring:* this refers to monitoring patterns and processes of changes in representative forest communities such as changes in provisioning of goods emanating from forest communities.
III. *Habitat level monitoring:* this includes monitoring of unique habitats that support specialized plant species and assemblages such as endemic rich alpine habitats, climate sensitive ecotone (e.g. timberline ecotone).
IV. *Landscape level monitoring:* it involves monitoring of representative pilot areas and or landscapes for their forest and plant diversity.

Table 1
Criteria and indicators for long-term ecological monitoring of forests in Indian Himalayan Region

System/component	Parameter/criteria	Indicators	Level of measurement
Forest	Basal area (growth)	Basal area increment	Species
	Composition	Changes in species richness, diversity and density	Community
	Occurrence	Elevation range/boundary shifts of species	Species
	Status of forest	Extent of habitat loss/fragmentation/area	Landscape
	Phenology	Change in leafing, flowering and fruiting time	Species
	Regeneration (tree)	Recruitment of seedling and conversion of saplings into trees	Species
	Endemics/nativity	Change in distribution pattern of native species	Landscape
	Rarity	Populations size and distribution	Landscape
	Vegetation Structure	Distribution of individuals among all age classes (seedlings, saplings and trees)	Species/community/landscape
	Productivity/biomass	Change in biomass and carbon sequestration	Species/community/landscape
	Invasion	Population density and abundance of alien species	Species/community /landscape
Soil	Moisture	Change in soil moisture	Landscape
	Nutrients	Change in major soil nutrients composition	Landscape
	Temperature	Change in pattern of soil temperature	Landscape
Socio-economic	Biomass removed	Amount of biomass removed (tree lopping, cut stumps), change in availability	Landscape

3.3. Procedure for establishment of LTEM plots

Realizing the gaps, Task Force 3 'Forest Resources and Plant Biodiversity' under NMSHE initiated establishment of LTEM plots in forest ecosystem to (i) ensure reliable and continuous availability of data on forest structure, species diversity and biomass across elevation gradients, (ii) analyze change in forest vegetation and plant diversity with changing climate and soil characteristics, and (iii) develop strong research base plans and strategies for conservation and sustainable utilization of plant biodiversity resources. Representative forested landscape of Uttarakhand, west Himalaya has been identified in district of Pithoragarh. Preliminary field sampling was carried out to collect information on the composition of forest vegetation types. Selection of sites for establishing LTEM plots was based on: (i) the representativeness, uniqueness and richness attributes of plant biodiversity, (ii) minimum anthropogenic disturbances (harvesting of fuelwood, leaf-fodder and grazing is minimal), and (iii) elevation range (1000–3800 m asl) to capture ecological responses of species to environmental changes along elevation gradient. Taking note of the outcomes of above sampling, a procedure for establishment of LTEM plots was designed. This include, (i) selection of representative forest sites, and demarcation of permanent plots with geo-coordinates, (ii) capturing photographic evidences of the plots, (iii) conducting vegetation sampling/inventory, (iv) selection and marking of tree species individuals within demarcated quadrats, (v) enumeration and analysis of plant species (nativity, endemism etc), (vi) assessment of tree regeneration patterns, (vii) collection and analysis of soil samples, and (viii) installation of soil temperature loggers. Following the standard global and national protocol published in earlier studies, LTEM plots were established in the representative forests at each climatic zone (i.e. sub-tropical to sub-alpine). All the plots were placed in relatively undisturbed forest stands along the elevation gradient (Table 2).

3.4. Monitoring and assessment of selected indicators

Assessment of indicators will be done by comparing the changes in the identified criteria and or parameters mentioned in the Table 1. Basic information on identified parameters was documented after establishment of LTEM plots. For vegetation assessment within each 1 ha plot selected, ten 10mX10m quadrats were laid and marked permanently for enumeration of trees and saplings and other details. Each 10mX10m quadrat was further subdivided into two 5mX5m sub-quadrats for enumeration of shrubs and seedling, and ten 1mX1m sub-quadrats for enumeration of herbs. Species richness was determined as the total number of species (tree, shrub and herb) in each plot. Plant samples were also collected from the study plots for herbarium preparation for further identification of plant species. Circumference at breast height (CBH) i.e. 1.37 m was measured for each individual tree in the sampled quadrats using measuring tape. All the woody individuals having CBH ≥ 31.5 cm were considered as trees; individuals with 10.5 to 31.4 cm CBH as sapling, and those with CBH less than 10.5 cm and height < 30 cm, were considered as seedling (Ralhan et al., 1982). Tree basal area, density and frequency were calculated following Misra (1968), Mueller-Dombois and Ellenberg (1974).

Indicators of biological importance and distinctiveness determined through analysis of species richness, representativeness (nativity) and uniqueness (endemism) following Samant et al. (1998). The species diversity index (Ħ) was calculated using the Shannon diversity index (Shannon and Weaver, 1963). Importance value index (IVI) was calculated for tree species as a measure of dominance, and nativity of plant species was determined following Samant et al. (1998). Based on nativity of the species, proliferation of non-native species was determined with the help of density and abundance data. Indicators of ecosystem health will be determined through assessment of forest ecosystem/landscape level features such as extent of habitat loss, habitat fragmentation, current and potential threats, etc following Reddy et al.

Table 2
Characteristics of LTEM plots established under NMSHE-TF 3 along elevation gradient.

Altitude (m asl)	Vegetation type	Locality	Latitude (N)	Longitude (E)	Dominant tree canopy species
1000	Deciduous sub-tropical broadleaved	Kanara	29.62801 to 29.62879	80.0947 to 80.09554	*Shorea robusta, Pinus roxburghii*
1500	Evergreen sub-tropical coniferous	Chitgal	29.666483 to 29.666916	80.0646 to 80.06565	*Pinus roxburghii*
1650	Evergreen temperate coniferous	Hat-kalika	29.656974 to 29.658867	80.048460 to 80.050467	*Cedrus deodara, Quercus leucotrichophora*
2000	Evergreen temperate broadleaved	Chodyar	29.638053 to 29.639124	80.036052 to 80.037276	*Quercus leucotrichophora, Rhododendron arboreum, Lyonia ovalifolia*
3250	Evergreen sub-alpine coniferous	Gunji	30.191027 to 30.194572	80.84875 to 80.85055	*Pinus wallichiana*
3800	Dry deciduous sub-alpine broadleaved	Kuti	30.19738889 to 30.29627778	80.75838889 to 80.75883333	*Betula utilis*

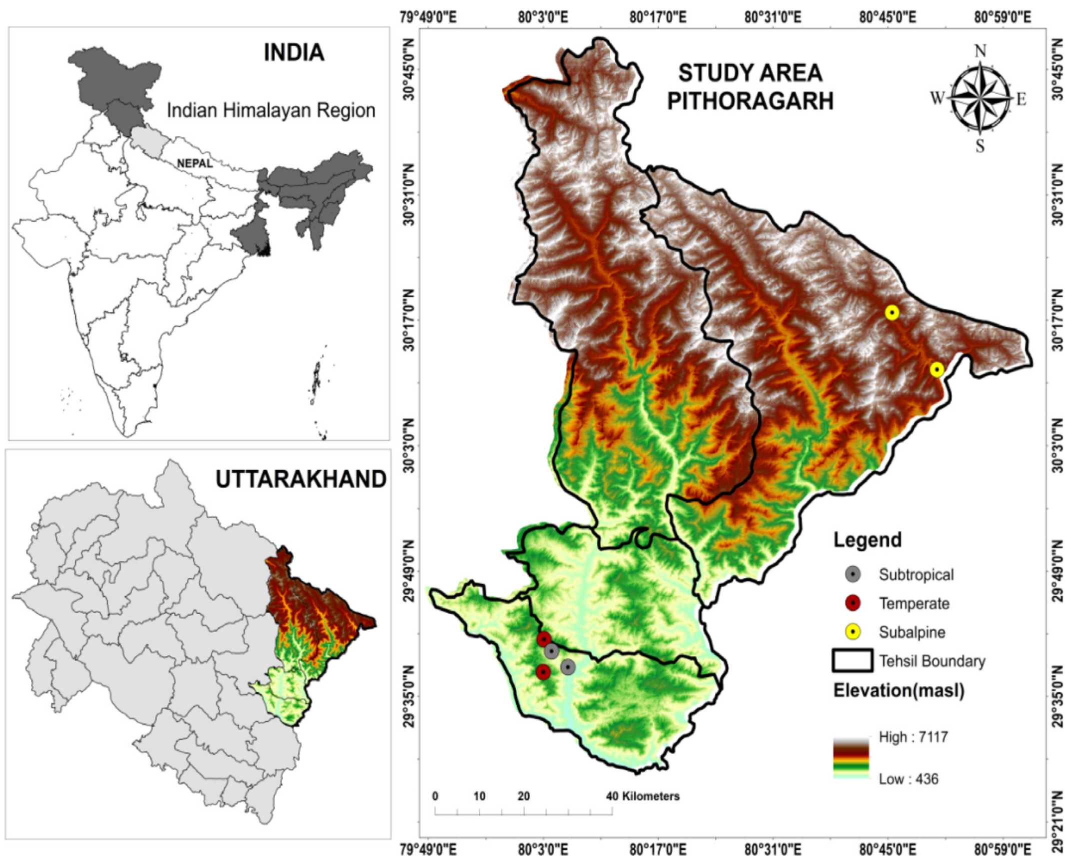

Fig. 2. Map of the study area showing Long-Term Ecological Plots.

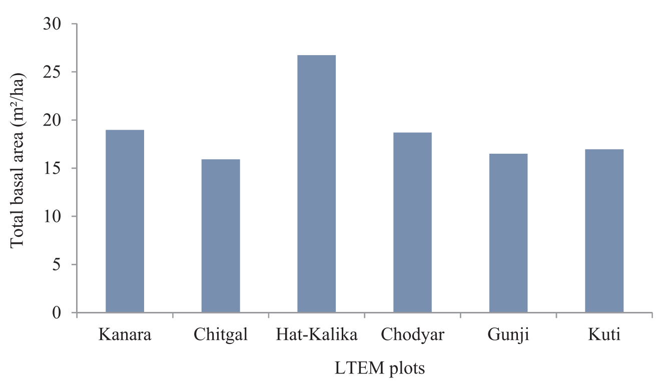

Fig. 3. Total basal area (m^2/ha) of tree species in the LTEM plots.

(2013).

The regeneration status of the sampled species was based on phytosociological data (Sankar, 2001). The basic CBH information of individual tree generated from each quadrat was used for development of population structures (Rawal et al., 2012; Gairola et al., 2014). The individuals of each tree species were grouped into seven arbitrary CBH classes (A: < 10; B: 11–30; C: 31–60; D: 61–90; E: 91–120; F: > 121–150; G: > 150 cm) for generating demographic profiles following Saxena and Singh (1984). Class A and B represent seedlings and saplings, respectively, and other classes (C-G) represent trees with different girth classes. The total number of individuals belonging to an individual class was calculated for each species in representative sites. The number of cut stumps and tree lopping were also counted for future comparison with the information compiled for next successive years.

Carbon based ecological indicators i.e. biomass, productivity and carbon sequestration are of particular importance because of their relationship to forest growth, ecosystem productivity and disturbances, and climate change. Biomass was estimated from diameter at breast height 1.37 m of individual tree using allometric regression for each tree developed by Chaturvedi and Singh (1987) and Rawat and Singh (1988) as follows:

$$\ln Y = a + b \ln X$$

where, Y = biomass per tree and X is the circumference at breast height, a = intercept and b = slope of regression and C-stock of standing dead tree will determined using the biomass value of tree species multiplied by a factor (C = Biomass × 0.47) following Magnussen and Reed (2004).

Soil temperature loggers have been installed at each LTEM plots to correlate the changes in soil temperature with changes in vegetation composition. Important soil nutrients were analysed for all the LTEM plots. Organic carbon estimation was done following method of Walkley and Black (1934). Total nitrogen was measured by using standard Kjeldahl procedure (Parkinson and Allen, 1975). Total soil phosphorus was determined by Olsen and Sommers (1982) method, and total potassium by Jackson (1958).

Once the spatial and temporal data on vegetation and other components are collected and analyzed after five years and so on, the standard modelling approaches and tools will be applied for assessing CC vulnerability of forests and changes in the forests of the region.

4. Baseline information of LTEM plots

A total of six LTEM plots have been established along elevational gradient (1000–3800 m) covering major climatic zone in Pithoragarh district of Uttarakhand, India (Fig. 2). The LTEM plots at lower altitude (1000–1500 m) in sub-tropical zone are dominated by *Shorea robusta* and *Pinus roxburghii*, and at temperate zone (1650–2000 m) by *Quercus leucotrichophora* and *Cedrus deodara* (Table 2). Two plots (i.e. one *P. wallichiana* dominated and another *B. utilis*) were established in

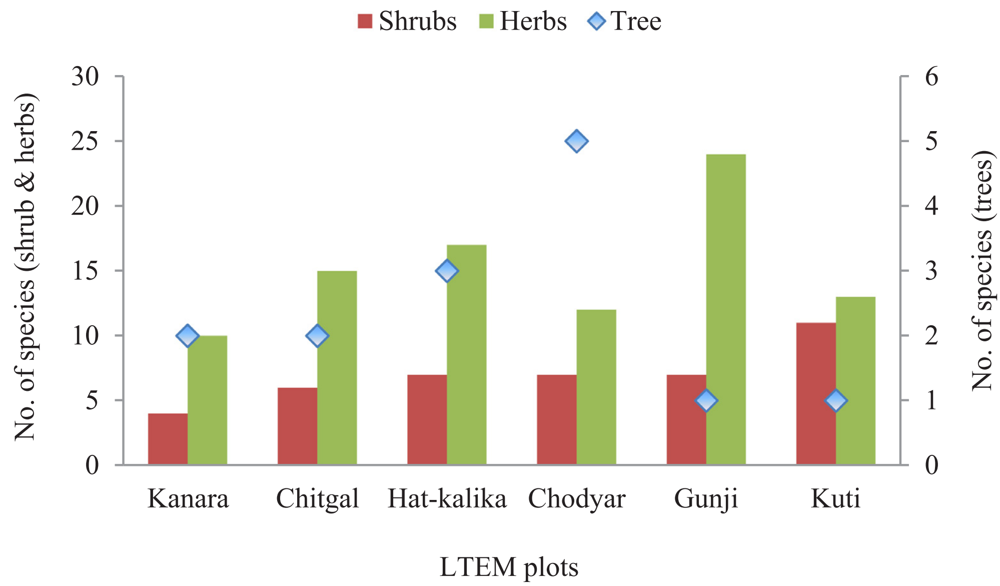

Fig. 4. Species richness of different life forms in the LTEM plots.

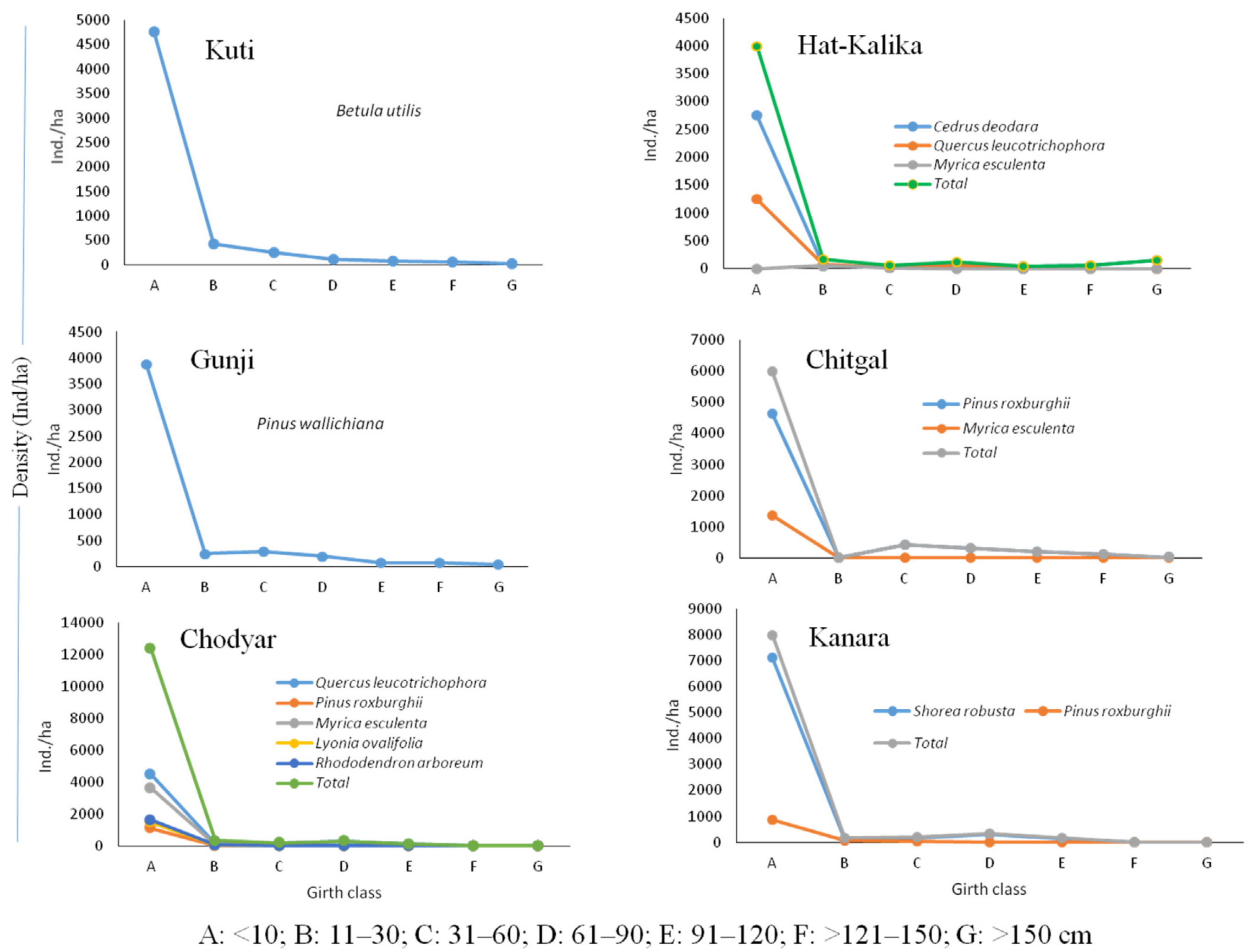

Fig. 5. Tree population structure of LTEM plots, western Himalaya.

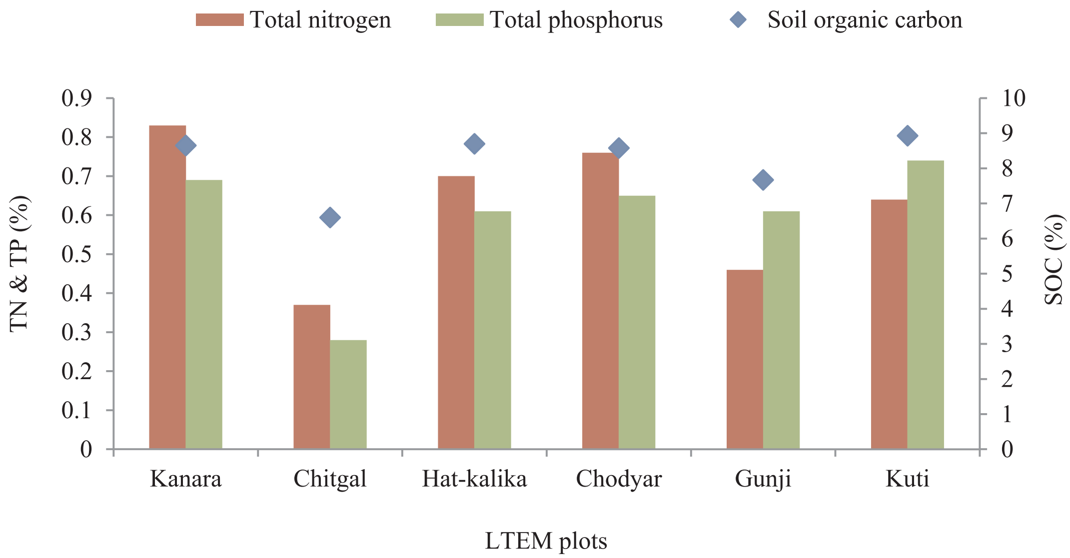

Fig. 6. Major soil nutrients in the established LTEM plots, western Himalaya.

timberline zone (i.e. sub-alpine forest zone) considering sensitivity of timberline ecotone to CC. Basal area increment is one of the important indicator for forest monitoring, hence basal area was documented for all the plots (Fig. 3). Among various expressions of diversity, understanding of species richness has remained a major focus of biogeographical researches (Rahbek, 2005). Species richness in present study was found maximum at 2000 m, and follows a general trend; unimodel pattern with mid-elevational peak (Fig. 4). The population structure of tree community provides distribution of individuals in different tree class (i.e. seedlings, saplings, adult trees), and also indicate health (regeneration) and stability of a particular forest in any region (Saxena and Singh, 1984; Tesfaye et al., 2002). Therefore, tree community structure of all LTEM plots was developed to compare with the long-term data to be collected in successive years (Fig. 5). The baseline information on major soil nutrients is presented in Fig. 6, indicates maximum nutrients at higher elevation (3800 m). All the plots thus established will be sampled periodically after five year, and data analyzed to enumerate the changes in selected parameters over time.

5. The way forward

Effective ecosystem management and biodiversity conservation requires a robust understanding and data sets on long-term dynamics of ecosystems. Forests and plant biodiversity in IHR is responding to environmental perturbations and anthropogenic pressures. However, documentation of these responses and likely consequences is meager due to limited access to data sets and unavailability of LTER/LTEM sites in the region. It is well investigated that LTER do not necessitate making any supposition about the past conditions, but will be useful in future assessment of subsequent monitoring. Therefore, it is important to develop monitoring protocol with suitable criteria and indicators for empirical field-based ecological studies, and disseminate use of such protocol for monitoring changes in biodiversity. Criteria and ecological indicators identified in the present study will, therefore, provide an opportunity to monitor and assess long-term ecological responses in forest ecosystems in the region. This approach will form the basis for promoting long-term studies on ecological responses to environmental changes. For example, the data generated over the years from LTEM plots established under NMSHE would be helpful in detecting the changes and trends in forest composition, plant species richness, diversity, forest community structure and bio-resource availability etc., w.r.t. climate change along elevation gradient. This will contribute to achieve envisaged biodiversity monitoring goals of India's NMSHE under NAPCC. The data generated from LTEM plots will also be valuable for developing future scenarios of change patterns using modelling and simulation tools to develop better conservation planning and Ecosystem based Adaptation Strategy for the region.

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